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WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/575

Metallurgical Examination of Defective and Satisfactory Helmets and Helmet Steel Stock Furnished by the McCord Radiator and Manufacturing Company, Detroit, Michigan

BY

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DATE 23 December 1943

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Watertown Arsenal Laboratory

Memorandum Report WAL 710/575

Partial Report on Problem B-7.3

-1-

23 December 1943

Metallurgical Examination of Defective and Satisfactory Helmets and Helmet Steel Stock Furnished by the McCord Radiator and Manufacturing Company, Detroit, Michigan

1. In the continuation of the investigation of the defects in Hadfield manganese steel which influence the breakage of M1 helmets both during various manufacturing processes and in service, eighty-six samples of defective and satisfactory helmets and helmet steel discs supplied by the McCord Radiator and Manufacturing Company, Detroit, Michigan, were examined at this arsenal.

2. Previous study of similar material supplied by the Schlueter Manufacturing Company of St. Louis, Missouri, indicated that helmet breakage and ballistic failures encountered at that plant were traceable to surface decarburization of the austenitic manganese steel resulting in the formation of brittle, martensitic surface layers and to laminations of martensite below the surface of the helmet steel probably resulting from residual ingot piping. The results of this preliminary study are contained in Watertown Arsenal Laboratory Memorandum Report No. WAL 710/571, 28 August 1943.

3. The following conclusions result from the examination of the material provided by the McCord Radiator and Manufacturing Company and from further examination of some of the Schlueter Manufacturing Company samples:

a. Breakage during forming of the subject helmets was caused by the following metallurgical defects:

1. Surface decarburization.
2. Undissolved carbides forming grain boundary networks.

b. Surface decarburization results in the formation of hard, brittle martensitic layers. The maximum observed hardness of the decarburized layer was 593 Knoop Hardness Number.

c. The "onion-skin" condition is not a reliable gage of surface decarburization. A characteristic mottled condition is observed on many decarburized discs but not on all.

d. The 180° bend test as described in paragraph E-1 of Specification AXS-645(Rev. 1.), "Helmet Steel, M1", if properly applied and interpreted is capable of rejecting much of the unsatisfactory steel being delivered to the helmet fabricators.

e. The results of the 180° bend test correlate well with the magnetic test developed at this arsenal. Metallographic examination substantiates both tests in all cases.

f. The Olsen cupping test, although capable of differentiating between satisfactory and defective steel, is not as practicable an inspection tool as either the 180° bend test or the magnetic test.

g. The spot welds of the special magnetic "U" type chin strap clips were consistently unsatisfactory. This is not attributable to inherently poor spot welding characteristics of austenitic manganese steel to low carbon steel but to poor welding technique employed upon the submitted samples.

h. Spot welding experiments performed at this arsenal indicate that both the 18-8 type of stainless steel and low carbon steel can be successfully spot welded to austenitic manganese steel. 18-8 stainless steel forms a spot weld approximately one-third stronger than does low carbon steel of the same gage spot welded to Hadfield manganese steel sheet.

i. Seven of the twenty helmets forwarded to this arsenal, after examination at McCord had ascertained they were free from cracks, were found to have edge cracks upon examination at this arsenal. This delayed cracking is believed associated with a condition of high residual stresses in a steel of high notch sensitivity.

4. The material received from the McCord Radiator and Manufacturing Company and some of the steel supplied by the Schlueter Manufacturing Company examined in the subject investigation is listed in Table I of the Appendix.

5. Details of the metallurgical examination are as follows:

a. Appearance of Surfaces of Helmet Discs

The personnel of the McCord Radiator and Manufacturing Company recognize certain surface conditions on helmet discs variously described as "onion-skin" or "rough surface" which they believe are associated with helmet breakage during the forming operations. In addition, they express the opinion that dents, excessive warpage and surface scratches on the helmet discs contribute to draw breakage.

Previous examination of helmet discs having both smooth and rough surfaces* revealed that the discs with rough surfaces were decarburized to the extent that layers of martensite up to 0.0017" thick were formed at the surfaces. Decarburization to this extent was found responsible for a lowering of the ballistic limit of the annealed discs by as much as 20% when tested with caliber .45 ball ammunition, and for increased helmet breakage during the forming operations.

Figure 1A is a photograph at a magnification of X2 of a portion of the surface of a helmet disc having a typically smooth surface. The fine parallel lines indicate the direction of rolling. Figure 1B is a photograph of the mottled condition observed on several of the previously examined helmet discs exhibiting a "rough surface". Figure 1C is a photograph of the surface of a helmet disc exhibiting an "onion-skin" surface. Metallographic examination of several discs having "onion-skin" surfaces revealed the absence of a decarburized layer. It is believed that this condition results from surface etching produced by a slight overpickling during the processing of the sheet steel, and is not considered deleterious, having been observed on many discs from which helmets have been successfully formed.

The mottled appearance, Figure 1B, has also been observed on numerous helmets supplied by both the Schlueter Manufacturing Company and the McCord Radiator and Manufacturing Company which broke during the drawing operation because of surface decarburization. There have been instances where decarburized discs did not exhibit a mottled surface but had smooth surfaces. The surface appearance is not, therefore, an entirely satisfactory gage of the presence of surface decarburization, although discs having a mottled appearance should be considered suspect.

The ten discs of series A and B (see Table I of the Appendix) were examined for surface condition and then subjected to magnetic** and microscopic examination. The results are contained in Table II of the Appendix. Of the five discs selected at the McCord plant as having poor surface conditions, only two are unsatisfactory because of metallurgical defects. The dented condition of two of the discs resulted from mechanical abuse, while the "onion-skin" surface of the remaining disc is not considered harmful. Of the five discs selected as having satisfactory surface conditions, three are of good quality, and two are decarburized to an extent believed capable of causing increased draw breakage. Of these two, one has a slightly mottled surface and one a smooth surface; demonstrating that the surface appearance alone is not a satisfactory criterion of the existence of decarburization.

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*Watertown Arsenal Laboratory Memorandum Report No. WAL 710/571, 28 Aug. 1943, pages 6-7.

**Watertown Arsenal Laboratory Memorandum Report No. WAL 710/571, 28 Aug. 1943, pages 7 and 8 and Figure 4 for details of the magnetic test.

b. Magnetic Test

The helmets of series C, D, E, F, G, and H (see Table I of the Appendix) were subjected to the magnetic test, and the results are contained in Table III. Previous magnetic tests which were supplemented by microscopic examination led to the conclusion that a traverse away from the vertical in excess of 10 inches represents a degree of decarburization responsible for poor deep drawing characteristics, while a traverse of less than 6 inches represents freedom from harmful decarburization. Cold working of the Hadfield steel does not change the magnetic properties of the steel sufficiently to appreciably affect the sensitivity of the magnetic test used at this arsenal to detect the presence of surface decarburization.

Nine of the 45 helmets subjected to the magnetic test showed traverses away from the vertical in excess of 10 inches. Of these nine helmets, five had cracked during the forming operations. The four remaining decarburized helmets which did not crack were all fabricated from steel supplied by the Carnegie-Illinois Steel Corporation. Previous magnetic and metallographic examination of Carnegie-Illinois helmet discs* indicated that steel produced by that company tends to be decarburized on one surface only, with the other surface essentially free from decarburization. If such discs are placed in the forming dies so that the decarburized surface becomes the inside surface of the helmet, the fine networks of cracks which form as the brittle martensitic surface layer is subjected to deformation are confined to the inside of the helmet and are not as dangerous as they would be if they were formed on the outside surface of the helmet. It would be expected, however, that the ballistic properties of such helmets would be adversely affected by the inner decarburized surface.

Helmet No. C10, which was successfully formed from Carnegie-Illinois steel found to be decarburized only upon the surface corresponding to the inside of the helmet, was ballistically tested with caliber .45 ball ammunition and found to have a ballistic limit of 824 ft/sec. Previous ballistic tests of Hadfield steel helmets** showed that good quality helmets have an average ballistic limit of approximately 1000 ft/sec., or 175 ft/sec. higher than that of helmet No. C10. This result is in agreement with other firing tests conducted at this arsenal which indicated that decarburized helmet steel has a ballistic limit as much as 200 ft/sec. lower than that of steel free from decarburization.

c. Bend Test

Paragraph E-1 of Specification AXS-645(Rev. 1.) "Helmet, Steel, M1" reads as follows:

"Steel. The steel shall withstand, without cracking on the outside of the bent portion; being bent cold through 180° flat back, in either direction."

*See Report No. WAL 710/571, page 6 and Figure 1B.
**Report No. WAL 710/439, 20 June 1942 and Watertown Arsenal Firing Record D-13, 6 September 1943.

For reasons unknown, the bend test as described in the specification is not applied as a routine test to check the steel quality either by the helmet fabricators or by the Ordnance Department.

To investigate the validity of the bend test, several steels which had previously been subjected to magnetic tests and microscopic examination, were investigated. These steels are as follows:

Disc No.	Helmet Fabricator	Fabricator's Lot No.	Mfgr. of Steel	Mfgr. Heat No.	Magnetic Traverse Inches	Results of Microscopic Examination
E1	Schlueter	62A	Sharon	72195	3.5	Excellent quality
4	Schlueter	63A	Sharon	72202	10.0	Spotty decarburization - .001" thick on both surfaces
CB	McCord	575	Carnegie	246803	11.0	Decarburized on one surface
SB	McCord	587	Sharon	72403	19.0	Decarburized - .0017" layers on both surfaces
C1	Schlueter	37B	Sharon	72044	37.0	Martensite lamination below surface of disc

Two three inch wide strips of the above steels were bent in the following manner. The strips were inserted in the jaws of a vise with approximately two inches protruding above the vise. The projection was hammered down to produce a 90° bend, and the bend was then continued in the jaws of the vise until the back surfaces of the strips were in contact. One strip of each steel was bent in one direction, and the second in the other direction, so that both surfaces of the steel were subjected to tension on the outside of the bends.

Photographs of the bend test samples of the five steels at magnifications of X2 and X5 are shown in Figure 2.

Steel E1 produced no cracks whatsoever on the outside of the bends of both specimens. This steel had been found to have satisfactory deep drawing characteristics, a low magnetic traverse, and complete freedom from decarburization.

Steel 4 showed only tiny cracks on the surfaces of both bends, and according to a strict interpretation of the wording of the specification probably represents a borderline rejectable condition. A magnetic traverse of 10 inches also represents a borderline rejectable condition. A close correlation is indicated between the bend and the magnetic tests. Steel from this lot (Sharon heat no. 72202) had produced helmets which failed the ballistic acceptance test because of the presence of martensitic surface layers resulting from decarburization.

Steel CB is of considerable interest. Metallographic examination had revealed the presence of decarburization on only one surface. The bend with the decarburized surface on the outside produced the cracks shown in Figure 2. The bend with the undecarburized surface on the outside produced an uncracked appearance similar to that obtained with steel K1. This experience emphasizes the necessity for conducting the bend test in both directions so that both surfaces of the steel will be equally subjected to the tensile stresses occasioned by the bending.

Steel CB would also be considered rejectable under the wording of the specification.

Steel SB cracked severely in both directions upon being bent. This steel showed a magnetic traverse of 19" and was decarburized on both surfaces, with 0.0017" thick layers of martensite being developed on the surfaces.

Steel C1 split open upon being bent. Metallographic examination revealed the presence of a lamination of martensite below the surface of the steel. This lamination probably originated in an ingot defect that was rolled out in the sheets.* This steel had a magnetic traverse of 37".

The bend test was also applied to strips cut from discs A1-A5 and B1-B5. The results checked the magnetic test; discs A1, A2, A3, B1, B2, and B3 forming no cracks and discs A4, A5, B4, and B5 cracking to the approximate extent shown by steels 4 and CB in Figure 2.

The results of the bend test indicate that strict application of this test is capable of rejecting steel which is decarburized or laminated to an extent having a deleterious effect upon the deep drawing and ballistic properties of Hadfield manganese steel sheet.

d. Olsen Cupping Test

The results obtained to date with the Olsen cupping test indicate that the quantitative value of the height of the cup at the moment of fracture is not always a reliable index of ductility in that defective steels have been occasionally found to have high Olsen numbers. The appearance of the cupped area does, however, present considerable information.

A steel free from metallurgical defects presents very smooth surfaces on the outside and inside of the Olsen cup, see Figures 3A and B. When a decarburized steel is subjected to the cupping test, a network of fine cracks similar to those formed in the bend test appears on both the outside and inside surfaces of the cup giving it a rough appearance, see Figures 3C and D. Figure 3D also shows the characteristic mottled surface appearance frequently associated with decarburization. Steel containing martensite laminations below the surface fracture in a very characteristic manner, see Figures 3E and F.

*See Report No. WAL 710/571, page 5 and Figures 1C and 1D.

Because the quantitative value obtained from the Olsen cupping test is unreliable for specification purposes, and the qualitative appearance duplicates to a less satisfactory degree the results of the bend test, the Olsen cupping test is not recommended for use as an inspection tool. The bend test is by far a simpler qualitative test, while the magnetic test is unsurpassed as a quantitative test.

e. Microscopic Examination of Helmets and Helmet Discs

Specimens for metallographic examination were prepared from discs A1, A2, A3, A4, A5, B1, B2, B3, B4, and B5, and from cracked helmets D1, D4, D6, E1, E2, F5, F6, and F8, see Table I.

The microstructures of discs A1, A2, A3, B1, B2, and B3 consisted of equi-axed austenite grains free of undissolved carbides and surface decarburization. The freedom from metallurgical defects would insure maximum deep drawing properties. The magnetic traverses of these discs varied from 0.5" to 6.0". Discs A4, A5, B4, and B5 were also free from undissolved carbides, but one surface of each of these discs was found to be irregularly decarburized, with martensite layers having a maximum width of 0.001" occurring at the surface. The martensite layers on all four discs were discontinuous, the discontinuities apparently coinciding with the mottled appearance shown in Figure 1B. The magnetic traverses of discs A4, A5, B4, and B5 varied from 8.5" to 10.5", which represents the borderline rejectable condition.

The cracked helmets examined in this investigation present two distinct metallurgical defects—surface decarburization, and undissolved grain boundary carbides. Of the helmets examined, D1 and D4 were badly decarburized, Figures 4A and B, and helmets D6, E1, E2, F5, F6, and F8 contained varying amounts of undissolved grain boundary carbides, Figures 4C and D. Small cracks which frequently occur in the martensitic layer of cold-worked decarburized helmet steel are shown in Figure 4B. The carbide grain boundary networks are believed to be the result of either too low an austenitizing temperature or too short a time at temperature, resulting in incomplete solution of the carbide in austenite. Exactly similar microstructures have been produced at this arsenal by quenching helmet stock from 1475°F.*

The low magnetic traverses of the helmets which broke because of the embrittling effect of grain boundary carbides illustrate the insignificant effect of both cold working and undissolved carbides upon the sensitivity of the magnetic test.

To confirm that the microconstituent occurring at the surfaces of decarburized helmet stock is martensite, Knoop hardness surveys were made on numerous cross-sections of decarburized material. Figures 5A and B are photomicrographs of Knoop hardness traverses across a section cut from helmet D4 which broke during the forming operation. The hardness

*WAL Report No. 710/430 "Helmets - Development of a Test for Hadfield Manganese Steel Helmets", Figures 3 and 4.

of the decarburized layer is 593 Knoop, while that of the cold worked base metal is 359-370 Knoop. The Knoop hardness numbers in this range are roughly equal to the Vickers Pyramid hardness numbers. Hardness surveys made on samples of decarburized helmet stock in the annealed condition show hardnesses of 336-395 Knoop in the decarburized layer and an average of 222 Knoop in the base metal. The decarburized surface layer probably consists of a mixture of austenite and martensite, the amount of martensite, and consequently the hardness, being a function of the extent of decarburization.

f. Microscopic Examination of Spot Welds of Special Magnetic "U" Type Chin Strap Clips

Helmets 01, 02, 04, and 05 were provided with special "U" type chin strap clips made from low carbon steel wire spot welded to the helmet bodies. They were forwarded to this arsenal for a study of the bond between the low carbon steel and the austenitic manganese steel and for comparison with the spot welds of the stainless steel chin strap clips used in production.

Previous examination of spot welds between the stainless steel chin strap clips and the helmets had disclosed many undesirable features tending to produce service failures of the welds. These features include weld porosity, interdendritic cracking in the fusion zones, and severe notch effects resulting from faulty design of the clip and the method of attachment.

The ferritic clips were apparently welded to the helmets with the same technique employed with the stainless steel clips normally used for this application. The welds had a very unsatisfactory appearance. Excessive pressure had evidently been exerted, resulting in the flattening out of the ends of the ferritic clips to such an extent that they were seriously weakened. For example, the clips on helmet 05 were readily broken off by grasping the rim of the helmet in the palm of the hand and pressing inward on the clip with the thumb. In addition, either too large a current or too long a time of application of current was used, resulting in excessively large heat affected zones. A cursory examination of the above factors indicates that a spot welding technique has to be carefully developed for each material. A technique producing satisfactory spot welds between 18-8 and Hadfield will not necessarily produce the same quality of weld between low carbon steel and Hadfield.

The eight spot welds on helmets 01 and 04 were prepared for microscopic examination. Without exception, all of the welds examined exhibited severe fusion zone cracking. Photomicrographs shown in Figures 6A, B, and C illustrate the extremely poor welds. The cracking was entirely confined to the austenitic steel, occurring at the boundary between the base metal and the molten pool of the weld.

The poor quality of these experimental welds does not necessarily prove that low carbon steel and austenitic manganese steel have inherently poor welding characteristics when spot welded together, but does prove that the welding technique employed was unsatisfactory. With this in mind, spot welding experiments were initiated at this arsenal to determine if low carbon steel can be successfully spot welded to Hadfield manganese steel.

g. Experimental Spot Welding of 18-8 Stainless Steel and Low Carbon Steel to Hadfield Manganese Steel

In order to evaluate and compare the strength and quality of spot welds between 18-8 stainless steel and austenitic manganese steel to welds between low carbon steel and manganese steel, tensile test specimens, as shown in Figure 7, were spot welded together and tested.

The 18-8 stainless steel and the low carbon sheet steel were procured in 17 gage (0.058") thicknesses. The Hadfield helmet steel stock consisted of good quality steel 0.044" thick, produced by the Sharon Steel Corporation, heat #72195, Schlueter lot #62A. The 5" x 1" strips of the various metals were sheared to size, and spot welded together with an Mieler, 5KVA, 550 volt spot welding machine. The current was applied for approximately 1½ seconds for each of the three spot welds, producing welds averaging 3/16" in diameter.

Six tensile specimens were made of each of the two metals against the austenitic manganese steel. Five of each were pulled in tension, and the sixth sectioned through the spot welds and prepared for microscopic examination. The tensile strengths of the individual specimens are contained in Table IV, and the average strength of the welds between the different materials are as follows:

Material	Breaking Load - Pounds (Average of Five Tests)
18-8 to Hadfield	3600
Low carbon steel to Hadfield	2750

In general the weld failures resulting from the tensile tests occurred by the pulling out of the weld beads from the Hadfield steel, the separation occurring in the heat affected zone of the Hadfield steel.

The results of the tensile tests indicate that either 18-8 or low carbon steel should prove satisfactory for application as helmet attachments providing the spot welding is conducted between two contacting parallel surfaces.

The microstructures of the spot welds between the different metals are shown in Figure 8 along with the results of Knoop hardness surveys through typical spot welds. Slight porosity is evident in some of the welds, as well as interdendritic shrinkage cracks in one of the stainless steel spot welds. Satisfactory spot welds can, however, be obtained with either material and the quality of the welds may be further improved by additional experimentation with various techniques.

h. Stress Cracking of Helmets

Preliminary work at this arsenal indicates the existence of high residual stresses in the helmets, both tensile and compressive, resulting from the severe cold working in the forming operations. Residual stresses in production helmets as high as 84,500 pounds per sq. inch have already been measured. Although the subject investigation is not directly concerned with the consideration of the effect of residual stresses upon the service life of helmets, some of the helmets studied in this investigation provide illuminating information regarding service behavior of helmets.

The twenty helmets of series G and H, see Table I, were forwarded to this arsenal in the drawn, trimmed, and spanked condition, without edgings or chin strap clips attached and unpainted. These helmets had been carefully examined at the McCord plant prior to shipment and were described as being entirely free from cracks. Shortly after receipt at this arsenal, the helmets were re-examined for defects. One or more cracks, varying in length from 0.3" to 2.0", were found extending from the rims of seven helmets. Details regarding the defects located on the helmets are contained in Table V.

It is believed that such cracking is associated with the highly stressed condition of a steel that is very notch sensitive. In many cases of service cracking, the crack is obviously associated with a notch, but in numerous instances, once the crack has occurred, the presence of the original notch cannot be verified. It is possible that, in many instances, very small edge cracks occur immediately upon trimming or spanking of the visor but pass undetected at the fabricator's plant and are subsequently covered up when the stainless steel edgings are fastened around the rim of the helmets. These cracks then grew longer with time due to a combination of high residual stresses resulting from cold working with the stresses occasioned by normal service.

The problem of service cracking is being investigated in greater detail, with several hundred cracked helmets returned from the field available for study. Some of the service cracking is definitely associated with the previously described metallurgical defects, namely, decarburization and undissolved carbides; some can be traced to severe notches in the edge of the helmet resulting from trimming with nicked dies, but the underlying cause is the highly stressed condition of the helmet shell resulting from an extremely severe cold forming operation.

6. It has been demonstrated that certain metallurgical defects are more or less commonly associated with commercially produced Hadfield steel helmet stock. These metallurgical defects have a very definite relation to the breakage of helmets, both during manufacturing and in service, and consequently must be entirely eliminated if the helmet is to be continued in production with its present design and manufacturing techniques. The adoption of a specification covering the quality of the steel purchased for the helmet application is the only method whereby metallurgically defective steel can be discarded.

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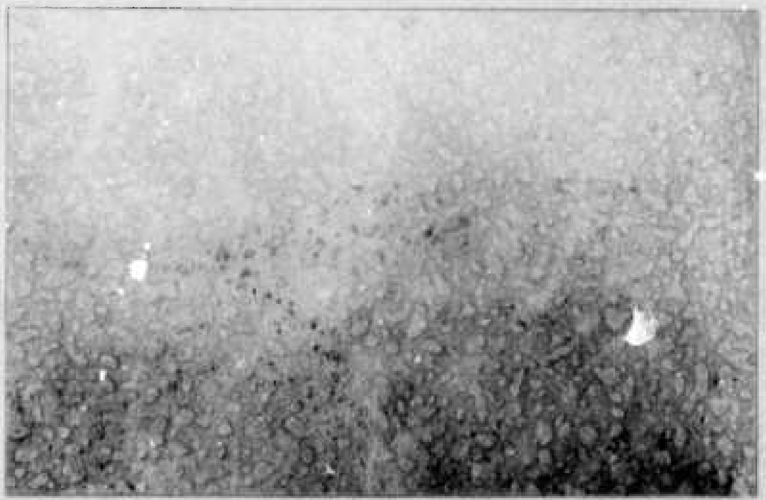
PHOTOGRAPHS OF SURFACES OF HELMET SHEETS

MAG. X2

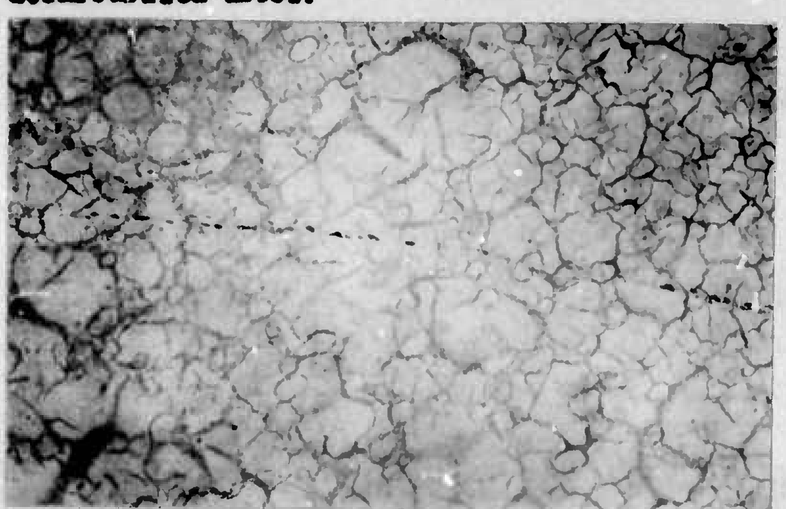
A

Steel E. Schlueter Lot 62A. Sharon Heat 72195.
No decarburization. Magnetic traverse - 2.5".
Surface typical of satisfactory helmet steel.



B

Steel CB. McCord Lot 575. Carnegie Heat 246803.
Decarburized steel. Magnetic traverse - 11.0".
Mottled surface condition observed on numerous decarburized discs.



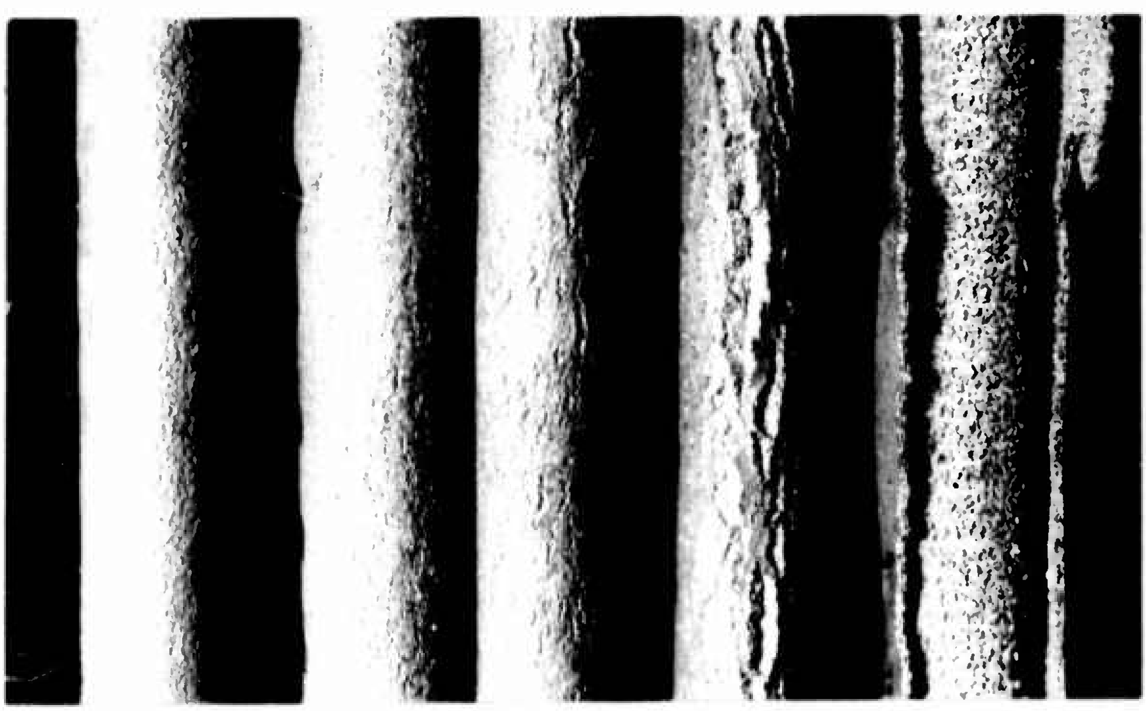
C

Disc A3. McCord Lot 596-C. Carnegie Heat 255799.
"Onion-skin" surface. Magnetic traverse - 4.5".
No decarburization. Surface condition probably caused by etching during pickling.

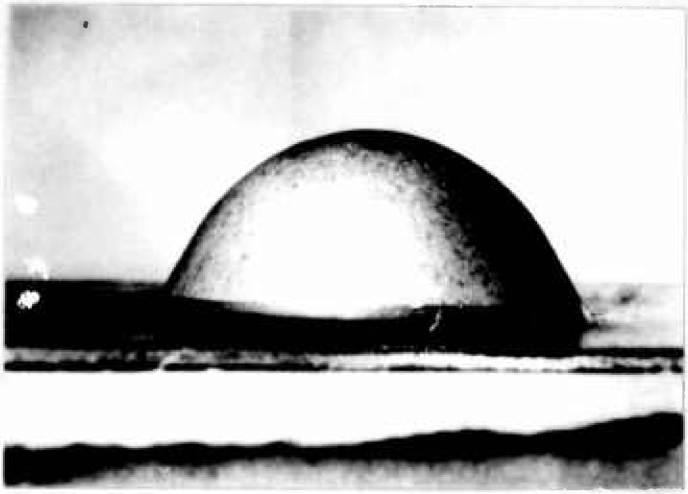
Mag. X2

E1 4 CB SB C1

Mag. X5

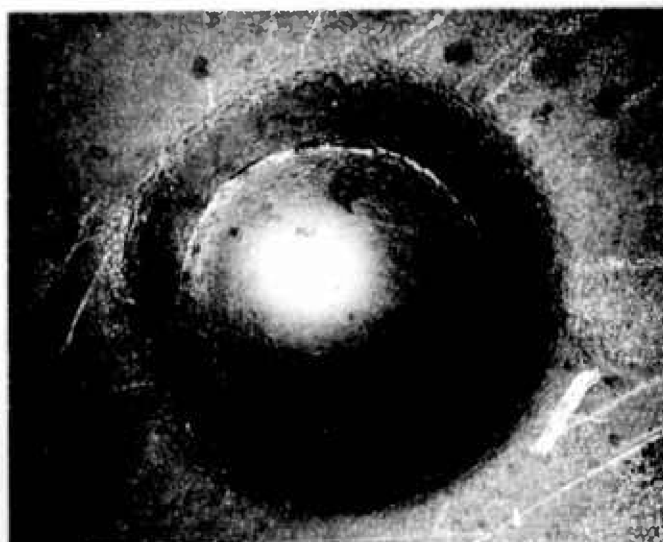


	E1	4	CB	SB	C1
Steel:	Schlueter 62A Sharon 72195	Schlueter 63A Sharon 72202	McCord 575 Carnegie 246803	McCord 587 Sharon 72403	Schlueter 37B Sharon 72044
Magnetic Traverse:	2.5"	10.0"	11.0"	19.0"	37.0"
Defect:	None	Decarburized	Decarburized	Decarburized	Lamination of martensite



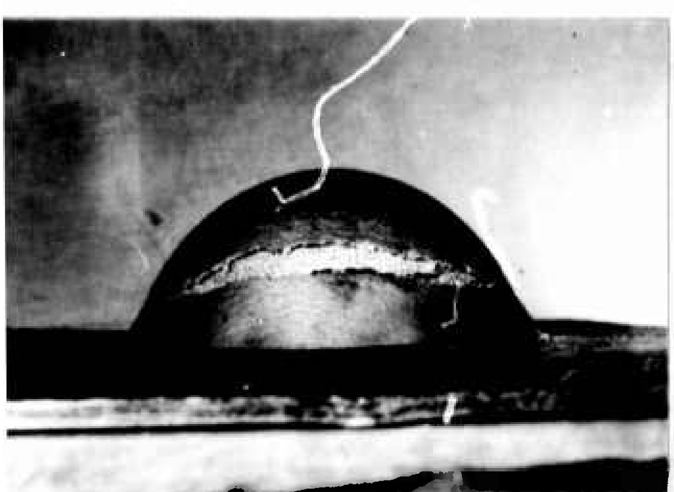

Side View -A- X2 Inside View -B- X2

Steel E - Schlueter Lot 62A, Sharon Heat 72195. Satisfactory steel. Appearance of cup prior to fracture. Surface of steel is smooth and free from cracks. Magnetic traverse - 2.5".

Side View -C X2 Inside View -D- X2

Steel A - Schlueter Lot 48A, Sharon Heat 72312. Decarburized steel. Appearance of cup after fracture. Surface cracking and jagged fracture typical of decarburized steel. Magnetic traverse - 15.0".




Side View -E- X2 Inside View -F- X2

Steel C1 - Schlueter Lot 37B, Sharon Heat 72044. Laminated steel. Appearance of cup after fracture. Cracking and separation of steel along laminations. Mag[illegible]
traverse - 37.0"

Microstructures of Helmets That Broke
in the Forming Operations

Nital Etch

-A- X250

Helmet D4, McCord Lot 544B, Carnegie Heat 255739. Martensitic surface layer resulting from decarburization. Width of layer - 0.0016". Magnetic Traverse - 23.0".

-B- X250

Helmet D4. Typical cracks in martensite layer resulting from deformation of brittle constituent.

-C- X1000

Helmet E1, McCord Lot 541C, Sharon Heat 72203. Network of undissolved carbides at grain boundaries. Magnetic Traverse - 3.0".

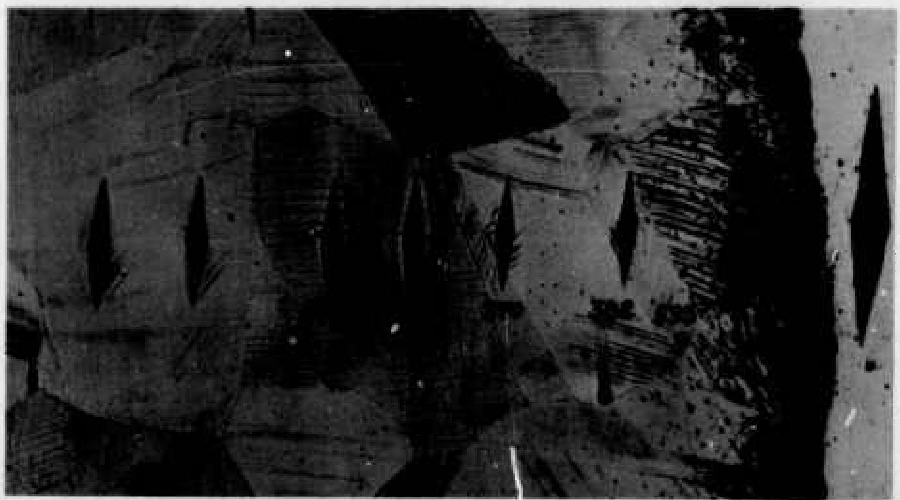
-D- X1000

Helmet E2, McCord Lot 549B, Sharon Heat 72198. Undissolved carbides. Magnetic Traverse - 1.0".

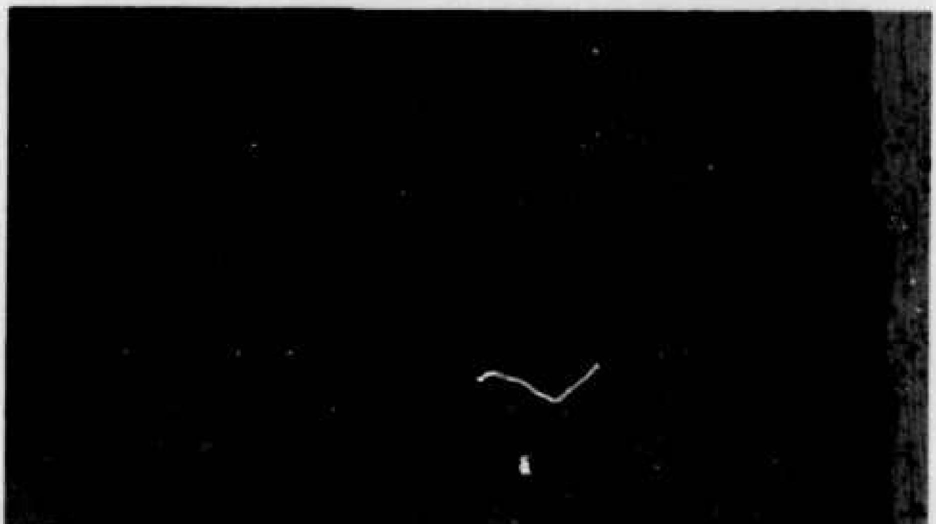
WTN.639-6105

FIG. 6

Knoop Hardness Survey of Decarburized Surface of Helmet that Broke in Drawing Operation



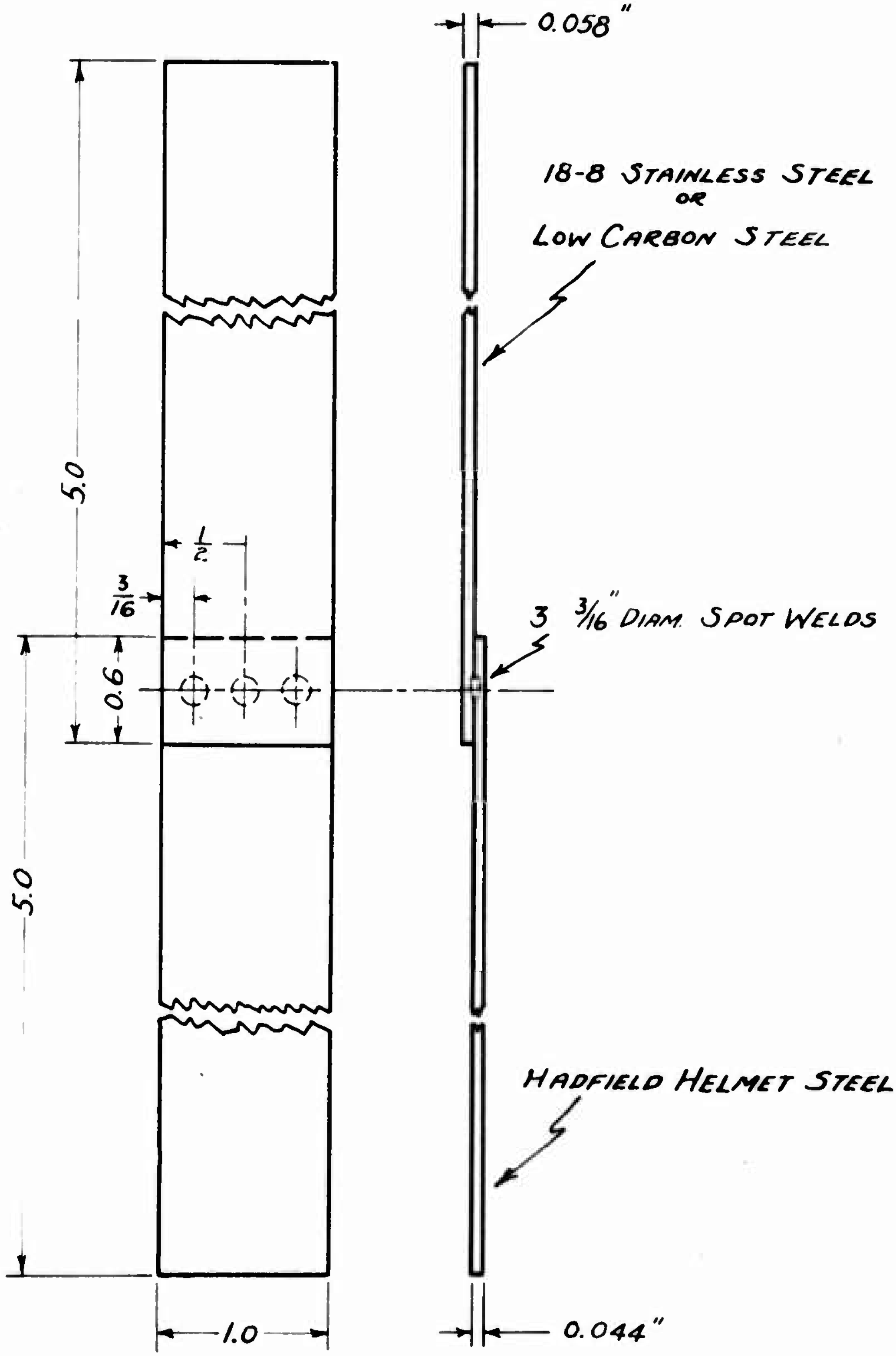
Nital Etch -A- X250
Helmet D4, McCord Lot 544B, Carnegie Heat 255739. Knoop Hardness Survey - 100 gram load.



-B- X500
Same as above. Average width of martensitic layer - 0.0016".

FIGURE 5

WTN.639-6166

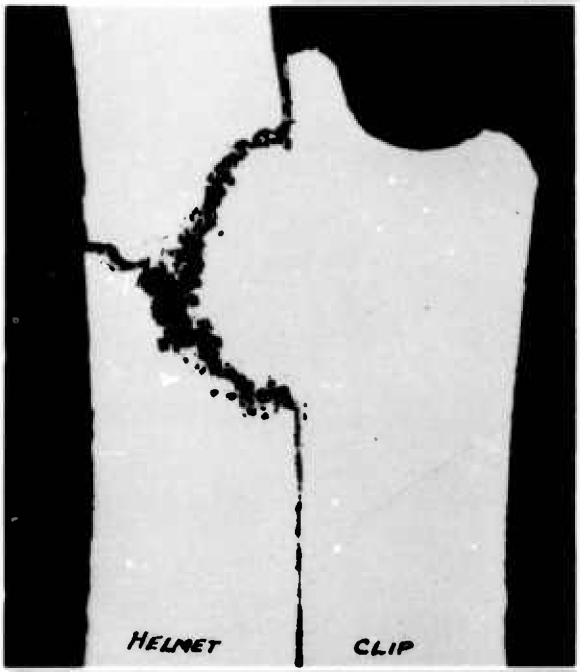


DETAILS OF SPOT-WELDED TENSILE
TEST SPECIMEN

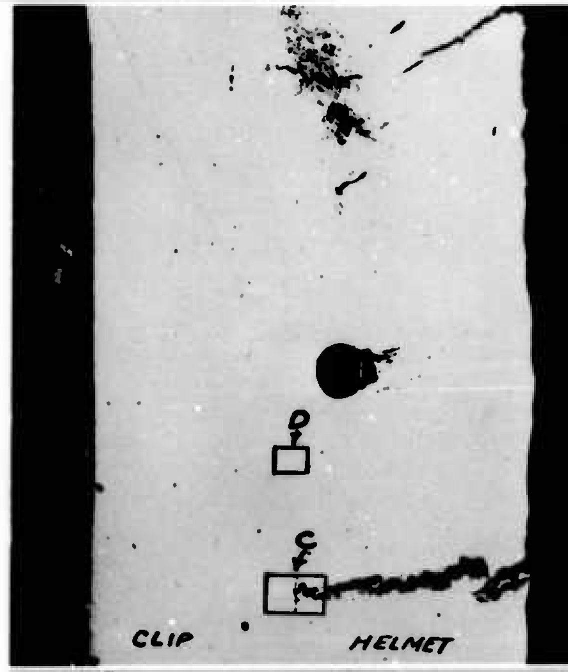
12-8-43 A.H.

FIGURE 7.

Microstructure of Spot Welds of Magnetic "U" Type Chin Strap Clips

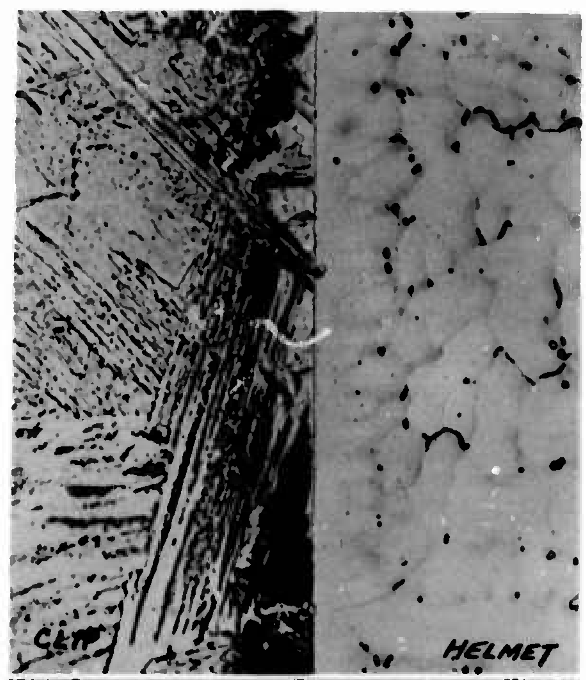


Unetched -A- X25
Helmet C4, McCord Lot 549B, Sharon Heat 72198. Severe fusion zone cracking in the Hadfield Steel. Very poor weld.



Unetched -B- X25
Helmet C1, McCord Lot 533A, Carnegie Heat 186917. Weld porosity and fusion zone cracking. Unsatisfactory spot weld.

Nital -C- X100
Helmet C1. Area shown in -B-. Severe cracking at boundary of base metal and zone molten during spot welding. Dendritic structure in molten region.

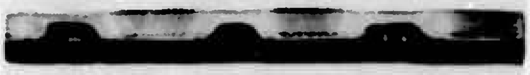


Nital -D- X1000
Helmet C1. Ferrite, pearlite, and martensite in magnetic steel clip. Cast structure showing coring in austeritic steel.

EXPERIMENTAL SPOT WELDS

LOW CARBON STEEL VS. HADFIELD

18-8 STAINLESS STEEL VS. HADFIELD

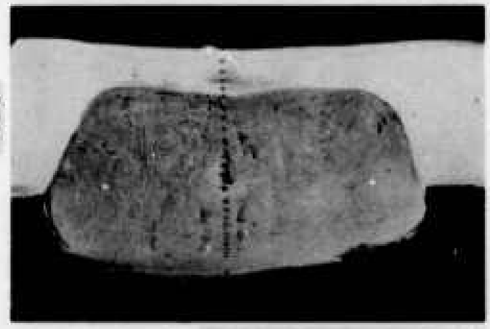


Etched in Nital Original Magnification X5

Low Carbon Steel

18-8

Hadfield

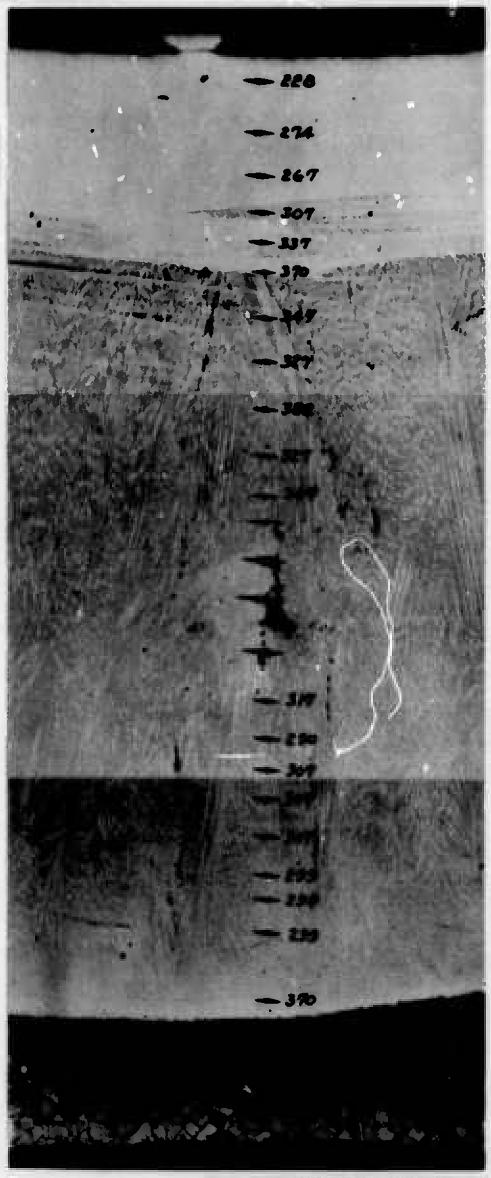


Original Magnification X25

KNOOP HARDNESS SURVEYS OF SPOT WELDS

Low Carbon Steel

18-8



Hadfield

Original Magnification X100

FIGURE

APPENDIX

TABLE II

Correlation of Surface Condition with Steel Quality

Disc No.	McCord Rating	*Magnetic Traverse Inches	Microstructure	Surface Condition
A1	Poor surface	0.5	Satisfactory - no decarb.	Dented
A2	Poor surface	2.0	" "	"
A3	Poor surface	4.5	" "	"Onion-skin" (Figure 10)
A4	Poor surface	8.5	Spotty decarburized layer up to 0.001" thick	Mottled (Figure 1B)
A5	Poor surface	10	"	"
B1	Good surface	2.0	Satisfactory - no decarb.	Smooth
B2	Good surface	6.0	" "	Smooth
B3	Good surface	6.0	" "	Smooth
B4	Good surface	9.5	Spotty decarburized layer up to 0.001" thick	Slightly mottled
B5	Good surface	10.5	"	Smooth

Discs A1-A5 rated unsatisfactory at McCord. May cause draw breakage due to poor surfaces.

Discs B1-B5 rated satisfactory at McCord. Good surface condition.

*Average of three tests.

Sample Group Letter	Sample Number	Source	Heat No. McCord	Heat No. Supplier	Lift No.	Description
H	6	Carnegie	619-B	246861	50818	
H	7	"	619-B	246861	50818	
H	8	"	619-B	246861	50818	
H	9	"	619-B	246861	50818	
H	10	"	619-B	246861	50818	

Disc No.	Source	Heat No. McCord	Heat No. Supplier	Description
-	Carnegie	612	177055	Disc, smooth surface.
-	"	612	177055	Disc, smooth surface.
CB	"	575	246803	Disc, rough surface.
-	"	575	246803	Disc, rough surface.
-	Sharon	603	72372	Disc, smooth surface.
-	"	603	72372	Disc, smooth surface.
SB	"	587	72403	Disc, rough surface.
-	"	587	72403	Disc, rough surface.
				Steel Supplied by the Schlueter Manufacturing Company
E1-10	Sharon	62A	72195	10 discs, from heat with satisfactory drawing properties.
3,4,5	"	63A	72202	3 discs, from heat with which drawing difficulties were experienced
C1-10	"	37B	72044	10 discs, defective because of laminations.
A1-10	"	46A	72312	10 discs, defective, improperly annealed.

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TABLE III

Magnetic Test of McCord Helmets

Helmet No.	Magnetic* Traverse Inches	Helmet No.	Magnetic Traverse Inches
C1	13.5	F1	0.5
C2	minimum - 8 maximum - 30	F2	2.5
C4	2.0	F3	7.0
C5	2.0	F4	6.5
C6	11.5	F5	1.0
C7	8.5	F6	7.5
C8	11.5	F7	1.5
C10	11.5	F8	1.5
		F9	8.5
D1	15.5		
D2	7.5	G1	0.5
D3	3.5	G2	0.5
D4	23.0	G3	1.0
D5	13.5	G4	1.0
D6	0.5	G5	0.5
		G6	1.5
E1	3.0	G7	0.5
E2	1.0		
E3	-	G8	1.0
E4	-	G9	0.5
E5	-	G10	1.0

Helmet No.	Magnetic Traverse Inches
H1	8.0
H2	5.5
H3	8.5
H4	7.0
H5	5.0
H6	7.5
H7	11.0
H8	5.0
H9	5.5
H10	9.5

*NOTE: Average of three tests, each at a different location on the helmet.

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TABLE IV

Tensile Strengths of Experimental Spot Welded Specimens

Specimen No.	Material	Breaking Load - Pounds
1	18-8 to Hadfield	3650
2	"	3200
3	"	3550
4	"	3750
5	"	3900
		Average 3600 pounds
6	Low carbon steel to Hadfield	2800
7	"	2650
8	"	3000
9	"	2850
10	"	2500
		Average 2750 pounds

See Figure 6 for dimensions of tensile specimen and details of spot welds.

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TABLE V

Defects Located on Helmets of Series G and H

Detected at Watertown Arsenal

Helmet No.	Description of Defect
G1	2.0" crack up from edge at 335°,* no notch
G2	-
G3	0.4" crack up from edge at 338°, at notch
G4	0.3" crack up from edge at 338°, at notch 0.3" crack up from edge at 8°, no notch
G5	-
G6	-
G7	-
G8	0.3" crack up from edge at 3°, no notch
G9	0.3" crack up from edge at 13°, no notch
G10	-
H1	-
H2	-
H3	-
H4	-
H5	-
H6	0.4" crack up from edge at 334°, at notch
H7	-
H8	-
H9	0.3" crack up from edge at 333°, no notch
H10	-

*Clockwise rotation, starting from the middle of the visor as 0°.